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IB 2005 / 50680

Patentanmeldung Nr. Patent application No. Demande de brevet n°

04100877.2

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des brevets

Anmeldung Nr:  
Application no.: 04100877.2  
Demande no:

Anmeldetag:  
Date of filing: 04.03.04  
Date de dépôt:

Anmelder/Applicant(s)/Demandeur(s):

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:  
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Waveguide structure for upconversion of IR wavelength laser radiation

In Anspruch genommene Priorität(en) / Priority(ies) claimed /Priorité(s)  
revendiquée(s)  
Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

Internationale Patentklassifikation/International Patent Classification/  
Classification internationale des brevets:

G02B6/00

Am Anmeldetag benannte Vertragsstaaten/Contracting states designated at date of  
filing/Etats contractants désignées lors du dépôt:

AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LU MC NL  
PL PT RO SE SI SK TR LI

**DESCRIPTION**

Waveguide structure for upconversion of IR wavelength laser radiation

The invention relates to waveguide structures, in particular to waveguide structures employed in diode laser pumped waveguide lasers, in particular in upconversion

- 5 waveguide lasers and their use as light source for replacement of a conventional arc lamp. Waveguide lasers employing a waveguide structure according to the present invention can be used as light source to replace conventional arc lamps such as for projection displays as well as for various lighting applications, e.g. headlight, shop, home, accent, spot or theater lighting.

10

- A laser diode is a semiconductor device that produces coherent radiation in which the waves are all at the same frequency and phase in the visible or infrared (IR) spectrum when current passes through it. Waveguide lasers comprise a laser diode as a pump source and a waveguide structure in which the pump radiation of the diode laser is
- 15 absorbed and converted to a different wavelength. Laser diodes and waveguide lasers are used in optical fiber systems, compact disc (CD), as pump source for solid state lasers, laser printers, remote-control devices, intrusion detection systems and for material processing like welding or cutting.

- 20 Thus diode lasers and in addition upconversion waveguide lasers and waveguide structures are generally known in prior art.

- However, there exists a long need to simplify the manufacture process of waveguide structures, especially waveguide lasers, in order to provide a waveguide structure with a
- 25 low vertical range of manufacture, a small number of components, increased robustness, improved compactness and low costs, in order to provide a light source which has superior performance characteristics.

It is the object of this invention to overcome at least some of the above drawbacks and to provide a waveguide structure, which is easier to produce, more compact and has better performance characteristics.

5 This object is achieved in a waveguide structure for upconversion of IR wavelength laser radiation comprising

a) at least one base substrate made essentially out of a moisture-stable, mechanically-  
and/or temperature-stable material

10

b) at least one active layer made essentially out of a halide glass, preferably a fluoride glass located on the base substrate layer

whereby the material of the at least one base substrate layer has a different composition  
15 from the material of the at least one active layer.

It has been found by the inventors that a waveguide structure with these features is easier to be produced, has fewer parts, especially fewer parts which require special diligence during the manufacture of the waveguide structure and has superior  
20 performance characteristics.

Furthermore it should be noted that both active and/or base layer can be either one single layer made out of one more or less uniform material or may comprise several sublayers and/or zones in which the material composition may change.

25

The term "active layer" as used in the present descriptions means in particular a layer structure that comprises a material that carries the incoupled IR light and the visible light emitted by the material, e.g. via rare earth metals contained therein, by an upconversion process of photon absorption and energy transfer followed by emission.

30

According to a preferred embodiment of the present invention, the efficacy of the waveguide structure is  $\geq 10\%$  and  $\leq 90\%$ , the efficacy being defined as

$$5 \quad \frac{\text{emitted power of usable radiation out of the end-faces of the waveguide structure}}{\text{IR-power absorbed in the waveguide structure}} * 100$$

and usable radiation being defined as upconverted light in the red, green and/or blue spectral range of the visible spectrum.

- 10 Preferably, the efficacy of the waveguide structure is  $\geq 15\%$  and  $\leq 90\%$ , more preferred  $\geq 20\%$  and  $\leq 80\%$ , even more preferred  $\geq 30\%$  and  $\leq 70\%$ , yet more preferred  $\geq 40\%$  and  $\leq 65\%$ , and most preferred  $\geq 50\%$  and  $\leq 60\%$ .

- 15 According to a preferred embodiment of the present invention, the thickness of the active layer is  $\geq 0$  and  $\leq 5 \mu\text{m}$ , preferably  $\geq 0.5$  and  $\leq 4 \mu\text{m}$  and most preferred  $\geq 1$  and  $\leq 3 \mu\text{m}$ . It has been found out, that by using an active layer with such a thickness, the efficacy of the waveguide structure as described above can be obtained more easily.

- 20 Furthermore, a waveguide structure employing an active layer with a thickness as described has a lower required power density. The required power density is the minimum power density that is needed for the active layer to conduct an upconversion process while acting as a laser. According to a preferred embodiment of the present invention, the active layer is pumped with a power density of  $\geq 0.1 - \leq 50 \text{ mW}/\mu\text{m}^2$ , preferred  $\geq 0.5 - \leq 20 \text{ mW}/\mu\text{m}^2$  and most preferred  $\geq 1 - \leq 10 \text{ mW}/\mu\text{m}^2$ .

25

This allows the use of wide ranges of IR-laser sources with the present invention.

Preferably the active layer material is selected out of a group containing:

- ZBLAN, consisting essentially of the components  $\text{ZrF}_4$ ,  $\text{BaF}_2$ ,  $\text{LaF}_3$ ,  $\text{AlF}_3$  and  $\text{NaF}$ , doped with one or more rare earth ions from the group Er, Yb, Pr, Tm, Ho, Dy, Eu, Nd or a combination thereof, or mixtures thereof; and/or
  - 5 one or more of the crystals  $\text{LiLuF}_4$ ,  $\text{LiYF}_4$ ,  $\text{BaY}_2\text{F}_8$ ,  $\text{SrF}_2$ ,  $\text{LaCl}_3$ ,  $\text{KPb}_2\text{Cl}_5$ ,  $\text{LaBr}_3$  doped with one or more rare earth ions from the group Er, Yb, Pr, Tm, Ho, Dy, Eu, Nd or a combination thereof; and/or
  - 10 one or more of the rare earth doped metal fluorides  $\text{Ba-Ln-F}$  and  $\text{Ca-Ln-F}$ , where Ln is one or more rare earth ions from the group Er, Yb, Pr, Tm, Ho, Dy, Eu, Nd or a combination thereof, or mixtures thereof.
- or mixtures thereof.
- 15 These materials have preferred characteristics for performing an upconversion process as desired. ZBLAN materials are further described in K. Ohsawa, T. Shibita, Preparation and characterization of  $\text{ZrF}_4$ - $\text{BaF}_2$ - $\text{LaF}_3$ - $\text{NaF}$ - $\text{AlF}_3$  glass optical fibers, Journal of Lightwave Technology LT-2 (5), 602 (1984).
  - 20 In case that doped materials are used, preferably the doping level of the active layer material and/or of one or more of the active layer material components is from  $\geq 0.01\%$  to  $\leq 40\%$ , from  $\geq 0.05\%$  to  $\leq 30\%$  and most preferably from  $\geq 0.1\%$  to  $\leq 20\%$ .
  - 25 The base substrate according to the present invention is preferably chosen from materials, which show one or more, preferably all of the following features:
    - only a minor absorption in the used range of wavelengths; preferably is the absorption of usable light over the total length of the waveguide structure  $\geq 0\%$  and  $\leq 50\%$ , preferably  $\geq 0\%$  and  $\leq 20\%$  and most preferred  $\geq 0\%$  and  $\leq 10\%$

- a weakening temperature of  $\geq 300$  °C and  $\leq 2000$  °C, preferably  $\geq 500$  °C, more preferably  $\geq 700$  °C, yet more preferably  $\geq 1000$  °C, and most preferred  $\geq 1200$  °C, and/or
- 5 - a weakening temperature difference between the active layer material and the base substrate material of  $\geq 50$  °C and  $\leq 2000$  °C, preferably  $\geq 100$  °C, more preferably  $\geq 200$  °C, yet more preferably  $\geq 300$  °C, and most preferred  $\geq 400$  °C; and/or
- a good surface handling; and/or
- 10 - a lower refractive index than the active layer material; preferably is the difference between the refractive index of the active layer material and the base substrate  $\geq 0.001$  and  $\leq 0.25$ , preferably  $\geq 0.002$  and  $\leq 0.15$ ; and/or more preferably  $\geq 0.005$  and  $\leq 0.05$ .
- 15 - good chemical resistance, especially moisture stability, which allows a better technical production of the waveguide structure.

According to a preferred embodiment of the present invention, the base substrate layer  
20 material is selected out of a group comprising quartz glass, hard glass,  $\text{MgF}_2$  and mixtures thereof. These materials fulfil all of the required and preferred features as set out above.

According to a preferred embodiment of the present invention, the active layer is coated  
25 on the base substrate layer by hot dip spin coating. The process of Hot dip spin coating is as such known in the art and e.g. described by Favre et al, SPIE Photonics West Conference, Paper 4990-21, San Jose, California, 25-31 January, 2003, which is fully incorporated by reference. In short, the process of hot dip spin coating process works by dipping an optionally preheated substrate first into a crucible of a molten material,  
30 which is to form the layer on the substrate. As the coated substrate is withdrawn from

the bath of the molten layer material, it is accelerated to a spin speed, usually about 2000 rpm, which throws off excess layer material and thins out the layer to the required thickness.

5 In this regard, the inventors have noted, that a base substrate, which has a weakening temperature of  $\geq 300$  °C and  $\leq 2000$  °C, preferably  $\geq 500$  °C, more preferably  $\geq 700$  °C, yet more preferably  $\geq 1000$  °C, and most preferred  $\geq 1200$  °C is most preferred to be used within this technique, since it allows to build up layers with reduced thickness on the base substrate. This for the reason that the layer, which is first build by dipping the  
10 base substrate in the molten layer material, is reduced to the wanted thickness by simply spinning the base substrate. This requires the molten layer material to remain in a somewhat liquid state during the spinning, because otherwise a further reduction of the layer cannot be achieved. Therefore the temperature of the base substrate when dipped into the molten layer material should be as high as possible as allowed by the temperature stability and viscosity of the layer material in order to enlarge the "time window"  
15 for thinning the layer on the base substrate. Of course the base substrate itself should not be affected by the hot dip spinning process. The inventors have found out, that for this reason, base substrates with weakening temperatures as set above are most preferred.

20 According to a preferred embodiment of the present invention, the length of the active layer is  $\geq 100$   $\mu\text{m}$  and  $\leq 100,000$   $\mu\text{m}$ , preferably  $\geq 200$   $\mu\text{m}$ , more preferably  $\geq 500$   $\mu\text{m}$  and most preferably  $\geq 1000$   $\mu\text{m}$  and  $\leq 50,000$   $\mu\text{m}$ ; and/or a width of the active layer is  $\geq 1$   $\mu\text{m}$  and  $\leq 200$   $\mu\text{m}$ , preferably  $\geq 2$   $\mu\text{m}$  and  $\leq 100$   $\mu\text{m}$ , and most preferred  $\geq 10$   $\mu\text{m}$  and  
25  $\leq 50$   $\mu\text{m}$ . Preferably the width of the active layer is  $\geq 0,1$   $\mu\text{m}$  to  $\leq 100$   $\mu\text{m}$ , preferably  $\geq 1$   $\mu\text{m}$  to  $\leq 50$   $\mu\text{m}$  larger than that of the laser source.

However, the length and width of the active layer should be chosen in that way, that:

30 - the IR radiation, which is impinged on the waveguide structure, is absorbed to an amount of  $\geq 50\%$ , preferably  $\geq 60\%$  and most preferred  $\geq 70\%$ ; and



dimensions of the waveguide structure match and/or are adapted to the IR radiation source.

- 5 According to a preferred embodiment of the present invention, the waveguide structure furthermore comprises a sealing layer located on the active layer in such a way, that the active layer is between the base substrate layer and the sealing layer, the sealing layer material being preferably selected out of a group comprising  $\text{SiO}_2$ , higher index of refraction materials, preferably  $\text{Al}_2\text{O}_3$ , and/or  $\text{Si}_3\text{N}_4$ , polymers, spin on glass or mixtures thereof, either alone or in combination with an optical isolation layer, preferably from undoped ZBLAN.

- 15 Since the preferred materials for the active layer are moisture-sensitive, it is preferred that the active layer is protected on both sides, first by the base substrate, which is moisture-stable and second by the sealing layer. By this design, a mass production of the waveguide structure can easier be obtained and the waveguide structure itself is more robust.

- Another object of the present invention relates to a lighting unit comprising at least one of the waveguide structures of the present invention being designed for the usage in one of the following applications:

- shop lighting,
- home lighting,
- accent lighting,
- 25 - spot lighting,
- theater lighting,
- automotive headlighting,
- fiber-optics applications, and
- projection systems.

Measurement Methods

Measurement methods for the terms used in this invention are known in the art;  
however, any skilled person may obtain them from one or more of the following  
5 documents, which are fully incorporated by reference

- J.F. Massicott et al., Electronics Letters, Vol. 29 (24), pp. 2119-2120 (1993),*  
*T. Sandrock et al., Optics Letters, Vol. 24 (18), pp. 1284-1286 (1999)*  
*« Rare Earth Doped Fiber Lasers and Amplifiers », Ed. Michel J.F. Digonnet,*  
10 *Verlag Marcel Dekker, Inc., especially p. 204 following*  
*A.C. Tropper et al., Journal of the Optical Society of America B, Vol. 11 (5),*  
*pp.886-893*

and further references cited therein.

15

CLAIMS

1. A waveguide structure for upconversion of IR wavelength laser radiation comprising  
a) at least one base substrate layer made essentially out of a moisture-stable mechani-  
cally- and/or temperature-stable material;  
b) at least one active layer made essentially out of a halide glass, preferably a fluoride  
5 glass located on the base substrate layer  
whereby the material of the at least one base substrate layer has a different composition  
from the material of the at least one active layer
2. A waveguide structure according to Claim 1, whereby  
10 the efficacy of the waveguide structure is  $\geq 10\%$  and  $\leq 90\%$ , the efficacy being defined  
as  
$$\frac{\text{radiated and/or emitted power of usable radiation out of the waveguide structure}}{\text{IR-power absorbed in the waveguide structure}} * 100$$
  
and usable radiation being defined as upconverted light in red, green and/or blue
- 15 3. A waveguide structure according to claim 1 or 2, whereby the thickness of the active  
layer is  $\geq 0$  and  $\leq 5 \mu\text{m}$ .
4. A waveguide structure according to claim 1 or 3, whereby the active layer material is  
selected out of a group containing:  
20 - ZBLAN, consisting essentially of the components  $\text{ZrF}_4$ ,  $\text{BaF}_2$ ,  $\text{LaF}_3$ ,  $\text{AlF}_3$  and  $\text{NaF}$ ,  
doped with one or more rare earth ions from the group Er, Yb, Pr, Tm, Ho, Dy, Eu,  
Nd or a combination thereof,

- one or more of the crystals  $\text{LiLuF}_4$ ,  $\text{LiYF}_4$ ,  $\text{BaY}_2\text{F}_8$ ,  $\text{SrF}_2$ ,  $\text{LaCl}_3$ ,  $\text{KPb}_2\text{Cl}_5$ ,  $\text{LaBr}_3$  doped with one or more rare earth ions from the group Er, Yb, Pr, Tm, Ho, Dy, Eu, Nd or a combination thereof,
  - one or more of the rare earth doped metal fluorides  $\text{Ba-Ln-F}$  and  $\text{Ca-Ln-F}$ , where Ln is one or more rare earth ions from the group Er, Yb, Pr, Tm, Ho, Dy, Eu, Nd or a combination thereof, or mixtures thereof.
- 5 or mixtures thereof.

5. A waveguide structure according to any of the claims 1 to 3, whereby the base substrate layer material has a weakening temperature of  $\geq 300^\circ\text{C}$  and  $\leq 2000^\circ\text{C}$  and/or has a lower refractive index than the active layer material.

10

6. A waveguide structure according to claims 1 to 5, whereby the base substrate layer material is selected out of a group comprising quartz glass, hard glass,  $\text{MgF}_2$  and mixtures thereof.

15

7. A waveguide structure according to claims 1 to 6, whereby the active layer is coated on the base substrate layer by hot dip spin coating.

20 8. A waveguide structure according to claims 1 to 7, whereby

- a length of the active layer is  $\geq 100\ \mu\text{m}$  and  $\leq 100,000\ \mu\text{m}$ , preferably  $\geq 200\ \mu\text{m}$ , more preferably  $\geq 500\ \mu\text{m}$  and most preferably  $\geq 1000\ \mu\text{m}$  and  $\leq 50,000\ \mu\text{m}$ ; and/or
- a width of the active layer is  $\geq 1\ \mu\text{m}$  and  $\leq 200\ \mu\text{m}$

25 9. A waveguide structure according to claims 1 to 8, furthermore comprising a sealing layer located on the active layer in such a way, that the active layer is between the base substrate layer and the sealing layer, the sealing layer material being preferably selected out of a group comprising  $\text{SiO}_2$ , higher index of refraction materials, preferably  $\text{Al}_2\text{O}_3$  and/or  $\text{Si}_3\text{N}_4$ , polymers, spin on glass or mixtures thereof, either alone or in combination with an optical isolation layer, preferably from undoped  $\text{SiO}_2/\text{Si}_3\text{N}_4$ .

30

10. A lighting unit comprising at least one of the waveguide structures according to one of the claims 1 to 9, being designed for the usage in one of the following applications:

- shop lighting,
- 5 - home lighting,
- accent lighting,
- spot lighting,
- theater lighting,
- automotive headlighting,
- 10 - fiber-optics applications, and
- projection systems.

ABSTRACT

Waveguide structure for upconversion of IR wavelength laser radiation

The invention relates to a waveguide structure for upconversion of IR wavelength laser radiation and is characterized in comprising

- 5 a) at least one base substrate layer made essentially out of a moisture-stable mechanically- and/or temperature-stable material
  - b) at least one active layer made essentially out of a halide glass, preferably a fluoride glass located on the base substrate layer
- whereby the material of the at least one base substrate layer has a different composition
- 10 from the material of the at least one active layer.

PCT/IB2005/050680

